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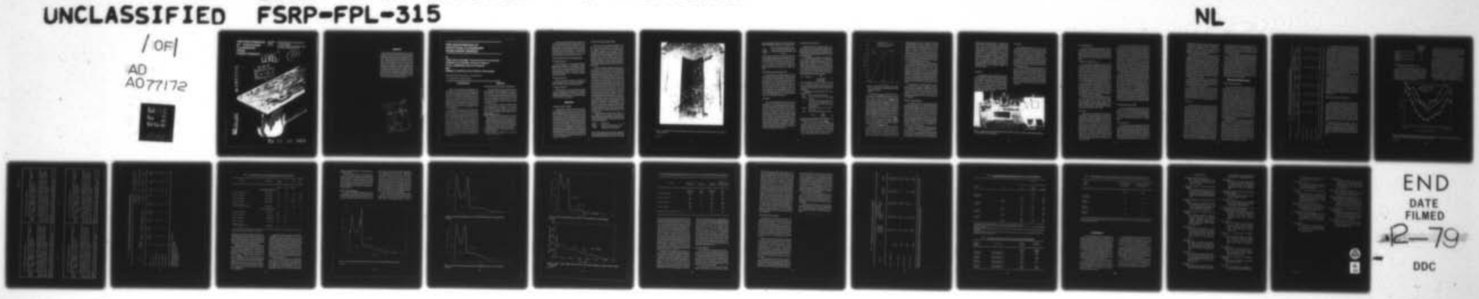

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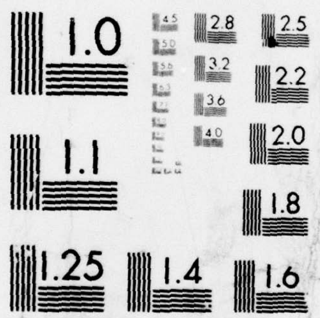

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FIRE PERFORMANCE OF STRUCTURAL FLAKEBOARD FROM FOREST RESIDUE

RESEARCH PAPER FPL 315

FOREST PRODUCTS LABORATORY
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
MADISON, WISCONSIN 53705

1979

Abstract

Fire performance properties were determined for the Forest Service (FS) structural flakeboard made from forest residues and for three commercial structural flakeboard products. Tests include fire endurance of wall systems, fire penetration, room corner-wall performance, 8- and 25-foot tunnel furnace, FPL rate of heat release, and smoke development by NBS smoke density chamber. Walls with the FS board met HUD Minimum Property Standards for a 20-minute exterior dwelling wall. The board also met Class B flamespread criteria, and in general, performed equal to or better than the commercial reference boards.

9 Research paper, 11 1979 12 25

6 # FIRE PERFORMANCE OF STRUCTURAL FLAKEBOARD FROM FOREST RESIDUE,

14 FSRP-FPL-315

By

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Introduction

The U.S. Forest Service has initiated a major research and development program on the feasibility of producing a structural flakeboard panel from the logging residues left in the forests (23).[3] This residue is estimated to be 3 to 4 billion ft^3 of wood per year. Structural panel board might be used for exterior wall and roof sheathing, and for subflooring and other floor systems, as future needs in housing expand. This would reduce projected shortages of lumber and plywood.

As a part of this program, the Forest Products Laboratory (FPL) has developed an experimental Forest Service structural flakeboard panel utilizing forest logging residues from the Pacific Northwest (18,23). More than 200 4- by 8-foot panels were made for a comprehensive physical and mechanical testing program. The research reported in this paper is intended to provide information on the fire performance of this board in comparison with three commercial structural flakeboards fabricated from wood mill residues or round wood. This information is intended to be useful in gaining acceptance by architects, builders, and code officials for this new product.

Material

Forest Service Structural Flakeboard

The Forest Service structural flakeboard in this evaluation was developed as a result of FPL research. It is a ½-inch-thick, three-layer, random-oriented flakeboard with faces of 0.02- by 1-inch-wide by 2-inch-long disk-cut flakes and core of 0.05-by random width by 2-inch-long ring-cut flakes. The face-core-face weight ratio was 15:70:15.

The residue mix used in preparing the flakes was primarily Douglas-fir, 75 percent >6-inch-diameter sound wood, 12½ percent sound wood containing some decay, 6¼ percent <6-inch-diameter sound wood and 6¼ percent bark.

[1]Authors' responsibilities for specific areas of the study were: C.A. Holmes, tunnel furnace and room corner-wall performance; H.W. Eickner (former project leader, now retired), planning and conduct of the study; J.J. Brenden, smoke yield and rate of heat release; and R.H. White, fire penetration and fire endurance. Recognition is given to C.A. Jackson, Engineer, who prepared the study plan while at the Forest Products Laboratory. He is now at Weyerhaeuser Company, Tacoma, Wash.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3]Underlined numbers in parentheses refer to Literature Cited at end of this report.

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The board was fabricated from flakes with 5 percent added phenolformaldehyde resin and 1 percent wax emulsion, based on ovendry flake weight. The prepared three-ply mat was pressed for 10 minutes at 350°F, with pressure to reach final board thickness in 1 minute. The final density of the board was 42 to 45 pcf (ovendry weight and volume at 65 pct RH).

Commercial Structural Flakeboards

Commercial Board A

Board A was a ½-inch-thick structural building particleboard or flakeboard. Larger flakes were in the core layer with smaller particles in the outer layers bonded with urea-formaldehyde resin at about 7 percent of the dry board weight. Board was of medium density range, 40 to 46 pcf.

Commercial Board B

Board B was the same as Commercial Board A except that it was phenolic bonded. It was marketed as exterior structural grade.

Commercial Board C

Board C was a ½-inch-thick exterior grade structural flakeboard building panel of medium density, averaging 40 pcf. It was made of aspen flakes bonded with phenolic resins at 3 to 4 percent of the dry board weight.

Methods

Tunnel Furnace Tests

Flame spread properties of the FS structural flakeboard and the commercial boards were determined by the 25-foot tunnel furnace test of ASTM E 84-70 (2) and the 8-foot tunnel furnace test of ASTM E 286-69 (4). These test methods also give comparative values on heat contribution and smoke development. Select-grade red oak flooring is the reference standard in both test methods. The test results from burning red oak are assigned a value of 100. The zero value is assigned to results obtained with asbestos cementboard (25-ft furnace) and asbestos millboard (8-ft furnace). The 25-foot furnace tests were conducted in the laboratory of the Hardwood Plywood Manufacturers Association, Arlington, Va.

FPL Room Corner-Wall Tests

The room corner-wall test, developed at the FPL in 1949, was used to simulate a "real fire" situation in the study of the performance of different materials in the 8-foot furnace (21,25). Correlation was good between the values obtained on these materials by the two test methods. The study of material fire performance by a realistic corner test has gained considerable interest in recent years to augment the results obtained by the smaller laboratory-scale tests including the 25-foot tunnel furnace (13,15,27).

In the FPL method, the test is conducted in the corner of an enclosed room, 8 feet wide by 8 feet high by 12 feet long. The test specimen was mounted in this corner (fig. 1). The two wall pieces are 2 feet wide by 8 feet high; a 5- by 5-foot area on the ceiling above the corner was covered by the specimen material. Ventilation is provided by an opening in the floor, and smoke and combustion gases are vented from the room through two flues at the top of the walls 5 feet either way from the test corner. The ignition source in the corner was a 5-pound wood crib of 20 hard maple sticks. The crib was ignited by burning 50 ml of alcohol. Temperature measurements were obtained with iron-constantan thermocouples at various locations on the specimen and in the room during the test. Continuous smoke measurements were obtained by light attenuation sensed by a 1P39, gas-filled phototube. Measurements were taken in the stack and across the center of the room at the 5-foot level. Radiant and convective heat energy from the fire corner was measured by a thin-foil calorimeter located in an adjacent corner.

Observations were made, after ignition, on the progress of the flames up the walls and across the ceiling to the flues. Flame spread indexes were calculated for the specimen materials by the following:

$$\text{Flame spread index} = \frac{100 \times 6 \text{ min}}{\text{(time in min for flames on test specimen to reach flues)}} \qquad (1)$$

The 6 minutes is the time required for flames on a red oak standard specimen to reach the flues. The flame spread index for red oak is thus 100

Figure 1.—Forest Service structural flakeboard specimen in place ready for test by FPL room corner-wall procedure.

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and for asbestos millboard 0. If flames do not reach the flues during the test of the specimen:

$$\text{Flame spread index} = \frac{100 \times (\text{maximum distance in excess of 5.5 feet reached by flames on test specimen in 6 minutes})}{7.5 \text{ feet}} \quad (2)$$

The 5.5 feet in equation 2 is the maximum distance reached by the flames from the wood crib on asbestos millboard. The 7.5 feet is the distance from that 5.5-foot point to the flues (8 − 5.5 + 5). Thus, 7.5 feet is the maximum distance that flame can travel over a specimen, beyond the flames from the crib, to reach the flues.

Smoke Density Chamber Test

In the evaluation of the fire performance of any material or group of materials, smoke yield is an important consideration. Hazards from smoke are the result of two basically different phenomena: First, smoke obscures vision so that means of fire escape are more difficult to find and fires are harder to fight; and second, smoke contains toxic substances which are life-threatening. Thus the potential smoke development from materials is an important factor in the understanding of how the materials will react to an imposed fire exposure.

Equipment

The structural flakeboards that comprise the group of materials being examined here were subjected to smoke yield determination in a closed, instrumented chamber that had been used for several preceding smoke studies (5,6,9). The chamber is an early version of an apparatus for smoke measurement developed by the National Bureau of Standards (NBS) (14), with a few of the modifications made in recent commercial models (17). Using the apparatus, smoke yield can be measured for both flaming and smoldering exposures. Specifically, the data will help answer the question of what the potential smoke yield is from each of a group of structural flakeboards.

Procedure and Calculations

Specimens for this study were 3 by 3 by ½ inch. Prior to smoke yield determinations, the specimens were conditioned to moisture equilibrium at 80°F and 30 percent relative humidity. The test procedure was similar to that used previously (6,9).

The calculation portion of the test procedure involved determination of a parameter known as the "specific optical density," D_s. The mathematical derivation of D_s has been discussed (5,6). Briefly, D_s is a characteristic smoke density parameter based on the length of the light path, the specimen area, the chamber volume, and the percentage of light transmitted through the smoke. For the specimen and apparatus used in this research,

$$D_s = 132 \log \left(\frac{100}{\text{percent light transmitted}} \right) \quad (3)$$

The calculations result in "smoke accumulation" or D_s-time curves (e.g., fig. 2). These curves describe the rate at which smoke accumulates in the chamber from fire-exposed test specimens.

Parameters and calculations from the D_s-time data are:

D_m	is the maximum value of D_s,
$t_{0.9D_m}$	is the time (min) when $0.9D_m$ occurs,
t_{16}	is the time at which $D_s = 16$ (room, 12 x 20 x 8 ft; burning area, 10 ft^2; light path length, 10 ft; 16 pct light transmitted),
SON_5	is the sum of D_s at 1, 2, 3, 4, and 5 min, and
SOI	is the "smoke obscuration index.":

$$SOI = \frac{D_m R_{av}}{100\, t_{16}} \quad (4)$$

where: R_{av} is the average rate of increase of D_s between the start of the run and $t_{0.9D_m}$.

When the specific optical density, D_s, reaches a maximum, that value is denoted by D_m. Because D_m relates to the maximum smoke yield (or maximum obscuration of vision) during relatively long fire exposures, it is important that, if the smoke yield of wood is to be reduced, the D_m parameter must be lowered.

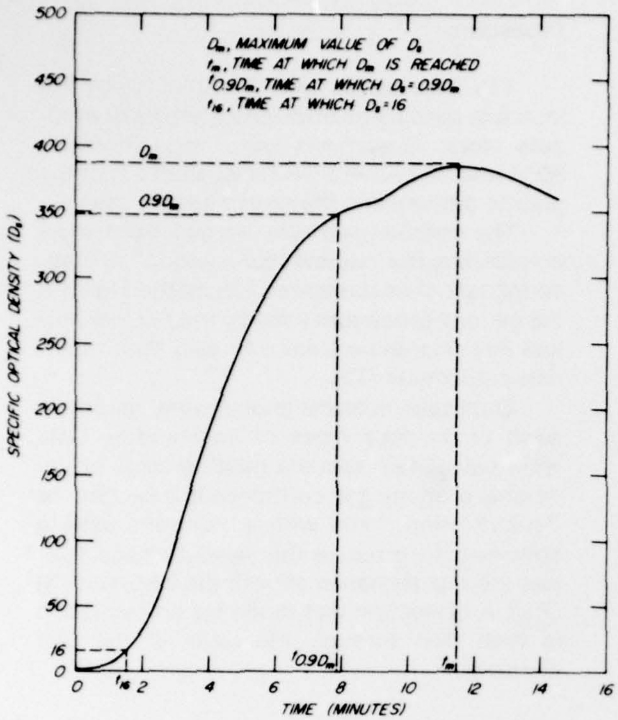

Figure 2.—Relationship of specific optical density to time (D_s-time curve) (typical of smoldering exposure).
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The parameter $t_{0.9D_m}$ is related to the time necessary for maximum smoke obscuration to occur. Thus, larger values of $t_{0.9D_m}$ show longer times to reach D_m, and hence longer time for escape and for firefighting. When this test method was being developed, it was common practice to report t_m, the time (in minutes) from the start of a test at which the maximum value of D_s (D_m) was reached (5). On accumulating experience with the smoke chamber, it became apparent that the D_s-time curves for many materials had plateaus in the region of D_m. Consequently, what is reported is $t_{0.9D_m}$, the time at which D_s reaches a value of $0.9D_m$. In the region of $0.9D_m$, D_s is usually changing rapidly enough with time to permit a more accurate estimate of $t_{0.9D_m}$ than t_m.

The time from the start of a run until $D_s = 16$ is the parameter t_{16} (in minutes). It is sometimes referred to as the "critical time factor" in smoke chamber work. As such, it enters into the calculation of the smoke obscuration index (SOI). The parameter t_{16} provides a convenient reference point at which to compare the flakeboards because it can be related to a model room. However, a criticism of the t_{16} value is the arbitrary nature of the hypothetical room on which it is based. In practice, for many materials, $D_s = 16$ is so low compared to D_m that t_{16} is very short and as a result, determining t_{16} from the D_s-time curves is sometimes a problem. Because t_{16} represents a critical time factor, low values are associated with relatively high smoke hazards and vice versa.

The smoke obscuration index was developed to represent the salient features of the D_s-time curves by a single number or index. Thus, materials could be compared by this test method using a single criterion. In formulating the SOI, the following factors were considered important in representing the smoke buildup in rooms: (1) The maximum smoke accumulation (D_m); (2) the average rate of smoke buildup, R_{av}; and (3) a critical time factor (taken as t_{16}). Low SOI values are desirable and high values are not.

The parameter "smoke obscuration number for the first 5 minutes"—SON_5—is another attempt to represent several features of the D_s-time curves by a single number. Here, the D_s values are taken at 1-minute intervals, and are added for the first 5 minutes of the run. This technique emphasizes the first short period of fire exposure.

Rate of Heat Release

In considering the fire hazards associated with any material, several characteristics might be listed: flammability, ignitability, potential for heat release, smoke yield, and others. One of the most important (although one of the least studied) is the rate at which the material releases heat during fire exposure. The rate of heat release is important because in a fire, there is an energy balance: If the rate of heat release is greater than the rate of heat losses to the surroundings, the fire will intensify; conversely, if the loss to the surroundings is greater, the fire will diminish.

In addition, code officials generally recognize that many materials will not pass the current definition of "noncombustible" in the model codes (1,10,16,20,24), but the materials will release only limited amounts of heat during the initial and critical periods of fire exposure.

There is also some criticism of using limited flammability to partially define "noncombustibility." Thus, at one time consideration was given to defining combustibility in terms of heat release based on a "potential heat" method (19), with the low levels used to define low combustibility or noncombustibility. This method measures the total heat release. It is generally agreed that a better or a supplementary measure of "combustibility" would be a determination of the rate of heat release. This would assess efficiently the relative heat contribution of materials—thick, thin, untreated, treated—under fire exposure.

Equipment

The apparatus used to determine the rate of heat release of the structural flakeboards in this research consisted of: a furnace in which one surface of the test material was exposed to fire (fig. 3a); a fuel-air mixture supply system (fig. 3b) for an exposure burner within the furnace; and instrumentation to control furnace operation and to record various responses (fig. 3c). (See also references 7,8).

Procedure

The flakeboards were cut into 18- by 18-inch test specimens from larger sheets of available stock. Specimens were conditioned at 80°F and 30 percent RH for at least 2 months prior to determining the rate of heat release.

The method used here can be looked on as constituting the "substitution method" of measuring rate of heat release. This method follows the general procedure used by the Factory Mutual Fire Insurance Company with their materials calorimeter (12).

Duplicate determinations were made on each of the four types of flakeboards. Data were calculated from the heating value of additional propane gas controlled in a second, or "substitution," run with a noncombustible specimen to produce the same furnace flue-gas thermal response as with the test material (7,8). A correction was made for any variation in heat flow through the walls of the test chamber.

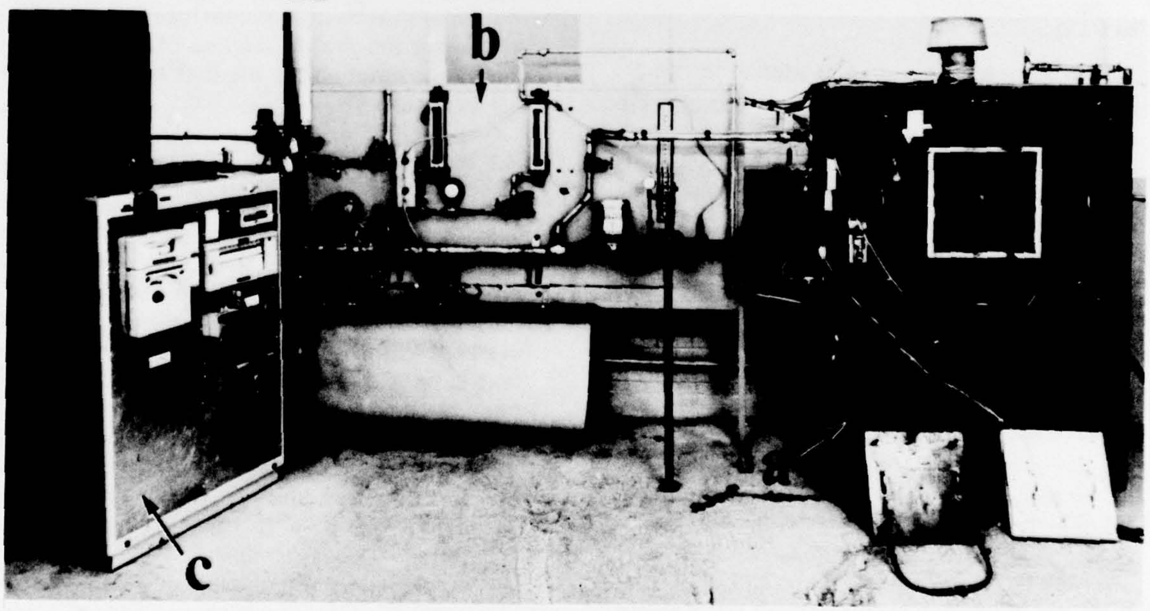

Figure 3.—Apparatus for measuring rate of heat release: Furnace, a; gas-air-water supply system, b; and electronic control cabinet, c.

Fire Penetration

The four flakeboards were tested for fire penetration in the FPL 20- by 20-inch vertical panel furnace using ASTM E 119 (3) time-temperature fire exposure conditions. The boards were tested as a solid material. Results of the tests were duration of fire resistance and char rate.

Equipment and Specimens

The vertical furnace had a 20¼-inch square opening on its side into which the specimen was inserted. Fiberglass insulation or high density mineral wool was used to fill the gap between the specimen and the edge of the furnace opening. The furnace was equipped with pipe outlets for discharging natural gas into the furnace. All air for combustion was admitted by natural draft through vents at the bottom of the furnace with baffling to get proper distribution.

Five 30-gage iron-constantan thermocouples were placed beneath asbestos pads on the unexposed side of the specimens. Locations were at the center of the panel and at the center of each quadrant. Inside the furnace, a single iron-capped and four semiprotected thermocouples were located on a plane 2 inches from the exposed surface of the panel.

The 20-inch-square test panels were either ½ inch or 2 inches thick. The 2-inch-thick specimens consisted of four plies of the ½-inch-thick flakeboard panels glued together with phenol-resorcinol glue. A 30-gage copper-constantan thermocouple was inserted between each ply at the center of the panel.

Procedure

The panels were subjected to fire exposure on one face. The gas supply of the furnace was regulated so that the temperature of the iron-capped thermocouple, opposite the center of the panel, followed the ASTM E 119 time-temperature curve. The gas was turned off when there was a burnthrough or flaming along the edges of the unexposed face of the panel. The panel was then removed and water applied to the exposed surface to extinguish any remaining flames or glowing. Measurements were made of the thickness of the uncharred wood remaining. During the tests, recorders monitored the temperatures indicated by the various thermocouples.

Fire-resistance times and char rate were determined in the one-ply tests. Fire resistance is a property characterized by the duration of exposure to time of failure. Failure is reached when the fire has burned through some part of the test specimen or when the thermocouples in contact with the outside surface of the panel indicate an average temperature of 250°F above the initial temperature or an individual temperature of 325°F above the initial temperature. Char rates were computed from the times of burnthrough or when a thermocouple indicated 550°F. Past work has indicated that the base of the char layer in solid wood can be characterized by a temperature of 550°F (22).

The results of the four-ply tests gave initial char rate, steady-state char rate, and average char rate. The times for thermocouples within the panel to reach 550°F were used to compute the initial and steady-state char rates. The initial char rate is the actual thickness of the ½-inch ply divided by the time that the thermocouple—about ½ inch from the fire-exposed surface—reached 550°F. The steady-state char rate is the slope of the line obtained by a least-square analysis of the time-distance data of the three thermocouples between subsequent ½-inch plies. The average char rate is either the thickness of panel charred divided by the duration of the fire exposure or the total thickness of the panel divided by the time of burnthrough.

Fire Endurance of Walls

The four flakeboards were used in load-bearing wood-frame walls tested for fire endurance in the Forest Products Laboratory large vertical furnace. The tests were conducted according to ASTM Standard E 119-73 (3) except for some modifications described in "Procedure."

Wall Construction

For each of the four flakeboards, two walls were tested with different interior facing. For one wall, the interior facing was ⅝-inch gypsum wallboard panels vertically applied to the frame with 1-inch-long, fourpenny, gypsum wallboard nails, spaced 8 inches on center. All joints were taped and covered with joint compound, and nailheads were indented and covered with joint

compound. One coat of latex paint was applied. For the second wall, the interior facing was the ½-inch-thick flakeboard panel vertically attached to the framing with sixpenny nails spaced 8 inches on center at edges and 12 inches at intermediate locations.

The rest of the construction was the same for both types of walls. The wall framing consisted of nominal 2- by 4-inch studs (marked "Eastern woods stud grade") spaced 16 inches on center and symmetrically across the frame with 1-inch-thick end studs spaced approximately 12 inches from adjacent studs to accommodate the 10-foot width. A double plate was used at the top and a single plate at the bottom. The plates were ponderosa pine-sugar pine, Standard or better. The plates were attached to the studs by end nailing with two sixteenpenny common nails.

Glass-fiber roll insulation, 3½ inches thick, with asphalt-impregnated paper vapor barrier was attached within the stud spacings. The tabs of the insulation were stapled to the 2-inch stud edges facing fire exposure.

For exterior sheathing, the ½-inch flakeboard panels were vertically nailed to the framing with eightpenny common nails, spaced 6 inches on center at edges and 12 inches at intermediate locations. Cedar bevel siding, ½ by 8 inches, was attached with sevenpenny siding nails to give 6 inches of horizontal exposure.

Procedure

The wall assemblies, 8 feet high and 10 feet wide, were constructed in the test frame of the wall furnace (11) at the Forest Products Laboratory. Panel height was limited to 8 feet and the applied load was 1,250 pounds per linear foot (the computed maximum loading for the first floor wall of a two-story house of average size). The load is greater than the maximum design load of 984 pounds per linear foot which is based on the compression of the plates. The allowable load for compression failure of the studs is 1,280 pounds per linear foot. The total load of 12,500 pounds was applied to the wall using the hydraulic jack system of the furnace frame. Five minutes after the application of the load, the furnace was ignited and the fire exposure conditions as prescribed in ASTM Standard E 119-73 were applied to the interior face. Observations were made of the furnace temperatures and pressures, temperatures on the unexposed face, panel deflection, time for burnthrough, time for structural failure, and condition of wall during test. Walls were tested until failure occurred.

The finish resistance, also called finish rating, of an interior fire-exposed facing material is often interpreted as a measure of the degree of protection provided by the facing material to the substrate materials and load-bearing members. The finish resistance of the interior flakeboard facing was determined by six thermocouples between the flakeboard on the fire-exposed side and the wood studs. The finish resistance was considered to be the time for the average of the six thermocouples to reach 250°F above ambient or a single thermocouple to reach 325°F above ambient.

Results and Discussion

Tunnel Furnace Tests

The flame spread values obtained in the two tests with the FS structural flakeboard in the 25-foot rating furnace were 70 and 72 with an average of 71 (table 1). This meets the acceptance flame spread criteria under building codes for class B material—75 or under flame spread. This classification will permit its use in many building occupancies, and applications where flame spread of building materials is limited; for example, in exitways and corridors. The heat contribution of 51 is low compared to red oak and the smoke developed of 165 is also acceptably low. The commercial boards obtained FSC values of 147, 127, and 189, and thus met the acceptance flame spread criteria for class C material—200 or under. Materials of this class are not permitted by most codes in many building types.

Densification of the surface is postulated as the reason for the lower flame spread obtained by the FS structural flakeboard compared to the considerably higher values obtained by the commercial boards. In an evaluation of the density gradients in a sample of 32 of the 200 plus FS boards, the density of the top surface increment ranged from 53 to 59 pounds per cubic foot (fig. 4). Density of the bottom surface increment ranged from 45 to 54 pounds per cubic foot. Average density of the 32 boards was 45 pounds per cubic foot.

Table 1.--Fire performance of ½-inch structural flakeboards in 8- and 25-foot tunnel furnaces[1]

Board	25-foot furnace (ASTM E 84)				8-foot furnace (ASTM E 286)			
	Board density	Flame spread classification	Fuel contributed	Smoke developed	Board density	Flame spread index	Fuel contributed	Smoke developed
	Pcf				Pcf			
FS structural flakeboard	44.6	71 (2.0)	51 (29.4)	165 (6.9)	42	97 (2.4)	95 (14.4)	260 (5.3)
Commercial Board A	46.5	147 (6.7)	110 (3.9)	135 (18.4)	39.2	96 (5.9)	102 (11.8)	184 (18.4)
Commercial Board B	46.6	127 (4.5)	100 (12.1)	189 (7.1)	41.8	96 (4.4)	92 (6.1)	228 (17.0)
Commercial Board C	42.6	189 (1.1)	134 (7.9)	123 (22.5)	44.8	119 (4.8)	138 (5.1)	163 (1.7)

[1]Fire test values are average of two tests except three tests for the FS structural flakeboard in the 8-ft furnace. Values in parentheses are coefficients of variations (pct).

The somewhat higher flame spread value of 97 average for the FS structural flakeboard in the 8-foot furnace compared to the 71 average in the 25-foot furnace cannot be fully explained (table 1). There are fundamental differences in the construction and operation of the two furnaces and test results on some materials do not always compare. However, with wood materials, the two furnaces usually rank the materials in the same order. This was true for the boards tested in this study. The commercial boards had flame spread values in the lower range of class C in the 8-foot furnace whereas in the 25-foot furnace the values were in the midrange. Commercial Board C had the highest flame spread by both test methods.

Smoke developed values were somewhat higher in the 8-foot furnace than in the 25-foot furnace. This is usually the case since the specimens in the 8-foot furnace are exposed to a radiant plate and a small pilot ignition flame which tends to promote nonflaming combustion and consequently high smoke development. In the 25-foot furnace the specimens are exposed to a large 4½-foot long impinging flame promoting greater flaming combustion and consequently less smoke.

FPL Room Corner-Wall Tests

The performance of the FS structural flakeboard and Commercial Boards A and B in the corner-wall tests were quite similar (table 2). Commercial Board C had a slightly higher flame spread, earlier ignition time, higher maximum heat flux, higher temperature development in the room, but less smoke development than the other boards. The somewhat higher flame spread of this Board C over the other boards was also obtained in the 25- and 8-foot furnace tests.

Although there were a limited number of specimens, the flame spread data can be used to obtain an estimate of the correlation between the different test methods. The best correlation of the flame spread data was obtained between the 8-foot furnace and the corner-wall test:

	Estimated correlation coefficient
25-foot furnace and 8-foot furnace	0.73
25-foot furnace and corner-wall test	.33
8-foot furnace and corner-wall test	.88

Smoke Density Chamber Test

Smoke yields from the four structural flakeboards and ⅜-inch-thick Douglas-fir plywood are given in table 3. In assembling the table, arithmetic means of three smoke-yield determinations were used at each combination of material and exposure (flaming or nonflaming). Determinations were in serial order.

Because of the importance of $\underline{D_m}$ values, table 3 gives the range of $\underline{D_m}$ as well as the arithmetic mean of $\overline{D_m}$ for the three replicate smoke determinations made on each combination of flakeboard and fire exposure.

Table 3 shows some rather wide variations in $\underline{D_m}$ values. Commercial Board B and Douglas-fir plywood tended to have lower maximum $\underline{D_m}$ while Commercial Board C had by far the highest D_m observed. With $\underline{D_m}$ in the range of 640 to 730, the corresponding light transmission for Commercial Board C is near the lower limit of measurement with this apparatus. Thus, using the criterion of maximum values for $\underline{D_s}$, under nonflaming fire exposure conditions, Commercial Board C is undoubtedly the smokiest material tested as a part of this study.

Table 3 shows that, in general, $\underline{D_m}$ results

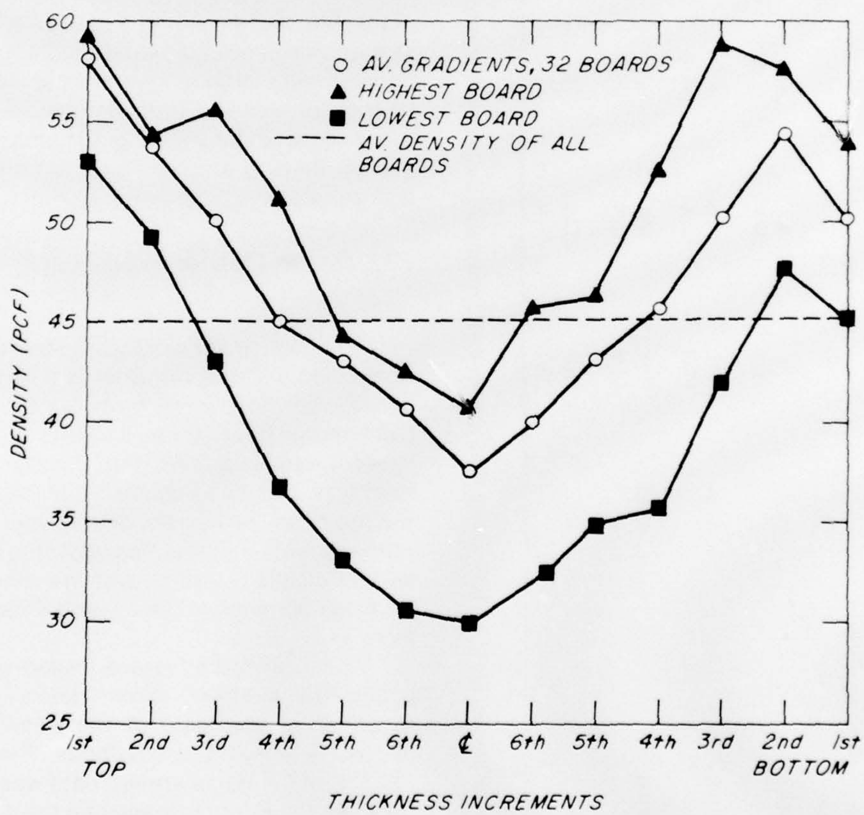

Figure 4.—Density gradients through panel thickness in FS structural flakeboards. Density is based on weight and volume at standard conditions (73°F, 65% RH).

(M 146 236)

U.S. Forest Products Laboratory.

Fire performance of structural flakeboard from forest residue, by C. A. Holmes, H. W. Eickner, J. J. Brenden, and R. H. White. Madison, Wis., FPL, 1978.
22 p. (USDA, FS Res. Pap. FPL 315)

Forest Service structural flakeboard made from forest residues and three commercial flakeboards were evaluated for fire performance in the 8- by 10-foot wall furnace, 20- by 20-inch fire penetration furnace, FPL room corner-wall, 8- and 25-foot furnaces, FPL rate-of-heat-release calorimeter, and smoke density chamber.

KEYWORDS: Fire endurance, fire penetration, room-corner-wall, flame spread, rate-of-heat-release, smoke.

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Table 2. - - Results of room corner-wall tests on ½-inch structural flakeboards and two reference materials

Board	Corner-wall flame spread index	Time wall ignited	Time ceiling ignited	Time flames reached flues	Maximum heat flux	Maximum light obscuration by smoke		Maximum temperatures obtained during test		
						Time	Percent of total obscuration	On ceiling in corner[1]	On ceiling at flues[2]	Center of room[3]
		Min	Min	Min	W/cm^2	Min	Pct	F	F	F
Red oak[4]	100	4.5	5.7	6.0	0.09	12.6	26	1,470	1,478	260
Asbestos millboard[4]	0	- -	- -	- -	.03	7.6	44	458	272	132
FS structural flakeboard[4]	106	4.2	5.2	5.8,5.5	.16	8.2	45	1,475	1,191	478
Commercial Board A[5]	98	4.6	5.7	6.1	.25	5.4	72	1,510	1,230	600
Commercial Board B[5]	102	4.6	5.7	5.9	.18	5.7	56	1,515	1,255	580
Commercial Board C[5]	113	4.1	5.1	5.3	.29	7.8	40	1,625	1,240	720

[1]On specimen surface, ceiling, in corner 6 in. from either wall.
[2]On specimen surface, ceiling, 1 in. from flue.
[3]In air, 3 ft down from center of room ceiling.
[4]Values are averages from two tests.
[5]Values are from one test.

Table 3. - - Smoke yield from four ½-inch structural flakeboards and a reference material[1]

Board	D_m (Range)	$t_{0.9D_m}$	t_{16}	SOI	SON
		Min	Min	Min^{-2}	
NONFLAMING COMBUSTION					
FS structural flakeboard	506 (487-521)	13.1	1.9	173	489
Commercial Board A	530 (510-549)	12.2	2.0	148	369
Commercial Board B	442 (418-480)	7.1	2.4	198	509
Commercial Board C	692 (641-729)	8.2	1.8	458	501
Douglas-fir plywood, exterior grade, A/C, 3/8-inch	440(376-494)	7.9	2.1	163	383
FLAMING COMBUSTION					
FS structural flakeboard	104 (84-134)	22.9	11.0	2	5
Commercial Board A	71 (36-90)	21.2	12.6	1	2
Commercial Board B	244 (134-333)	18.5	11.1	11	5
Commercial Board C	110 (94-138)	22.3	16.4	1	0
Douglas-fir plywood, exterior grade, A/C, 3/8-inch	106 (60-159)	13.5	8.1	3	15

[1]Each value is the mean of three test runs in serial order.

are lower for flaming fire exposure than for nonflaming exposure. This observation is typical of wood and wood-base products. Also shown is that Commercial Board B gave a somewhat higher D_m measurement under flaming conditions than the other four materials tested.

Table 3 shows that the FS structural flakeboard and Commercial Board A have the longest times to $D_s = 0.9D_m$ under nonflaming exposure. Commercial Board C, Commercial Board B, and Douglas-fir plywood have a much shorter $t_{0.9D_m}$, indicating that they tend to reach D_m more quickly. During flaming exposure, Douglas-fir plywood had the shortest $t_{0.9D_m}$ while the other four materials tended to have relatively long times to reach $D_s = 0.9D_m$. All of the materials tested tended to have a shorter $t_{0.9D_m}$ under nonflaming than under flaming exposures.

Inspection of table 3 shows that Commercial Board B has the highest t_{16} value under nonflaming exposure conditions. Under these same conditions the other four materials had t_{16} times that were nearly equal but shorter. The variation among the four is probably not significant. Under flaming exposure conditions Commercial Board C has the longest t_{16} time while the other materials reached $D_s = 16$ more quickly. It is typical for most woods and wood-base materials that they have shorter t_{16} times resulting from nonflaming exposures that result from flaming exposures.

Under nonflaming exposures, Commercial Board C had a much higher smoke obscuration index, SOI, than the other test materials (table 3). Typically, all of the flakeboards had a much lower SOI under flaming exposure, with even the highest value of 11 for Commercial Board B

being low compared to the corresponding nonflaming exposure.

Commercial Board A and Douglas-fir plywood had the lowest SON_5 under nonflaming exposure (table 3). Under these conditions the other three test materials tended to release their smoke more quickly. Under flaming exposure the SON_5 for all the materials was very low, this being typical for wood and wood-base materials in general.

Rate of Heat Release

In these rate-of-heat-release studies, there was relatively little difference among the four types of flakeboards (figs. 5-9; table 4). In all of the figures, there is a period of time from zero (when the specimen was inserted in the specimen opening) to the time when measurable heat release rates begin to occur. This is the "induction" period during which the specimens absorb enough heat to raise their temperatures to the point at which active burning with exothermic chemical reactions can proceed. During this period it is probable that negative rates of heat release can be observed; the physical significance of the negative rates is that, in this case, heat is being absorbed by the specimen rather than being liberated.

Under the exposure conditions generated in the FPL rate-of-heat-release apparatus, the heat release curves tend to have two distinct peaks with a valley between them. The first

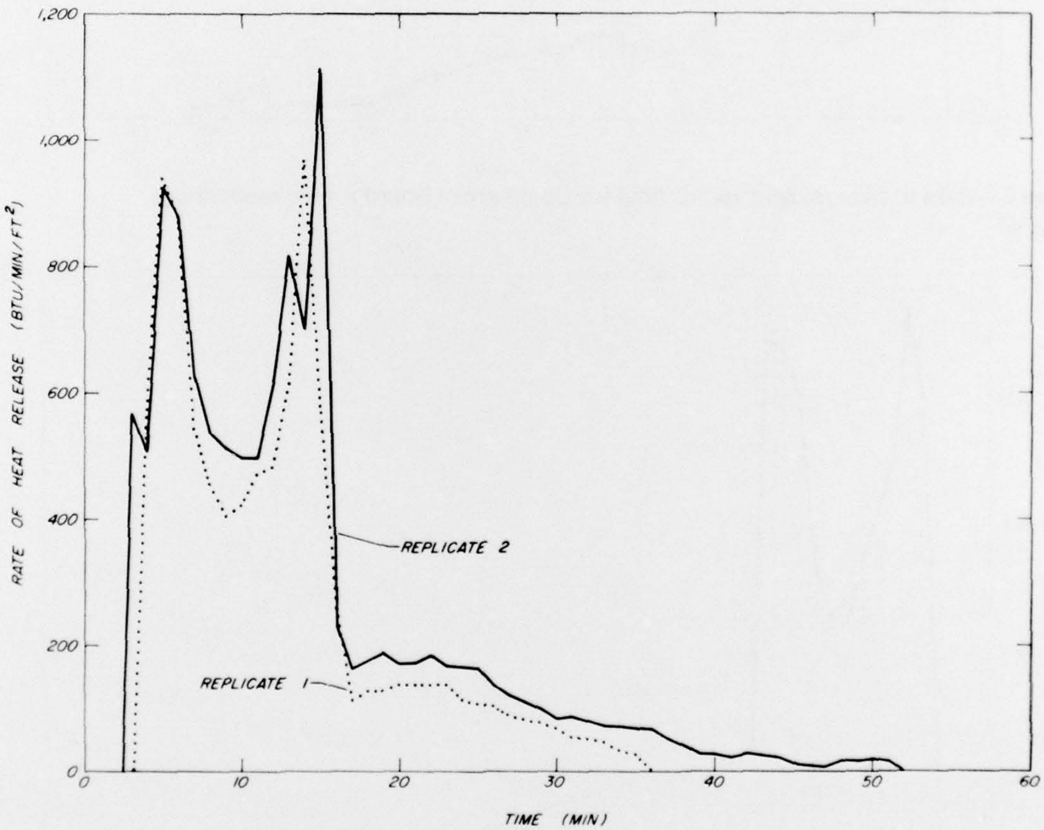

Figure 5.—Rate of heat release versus time for FS structural flakeboard (two replicates).

(M 146 066)

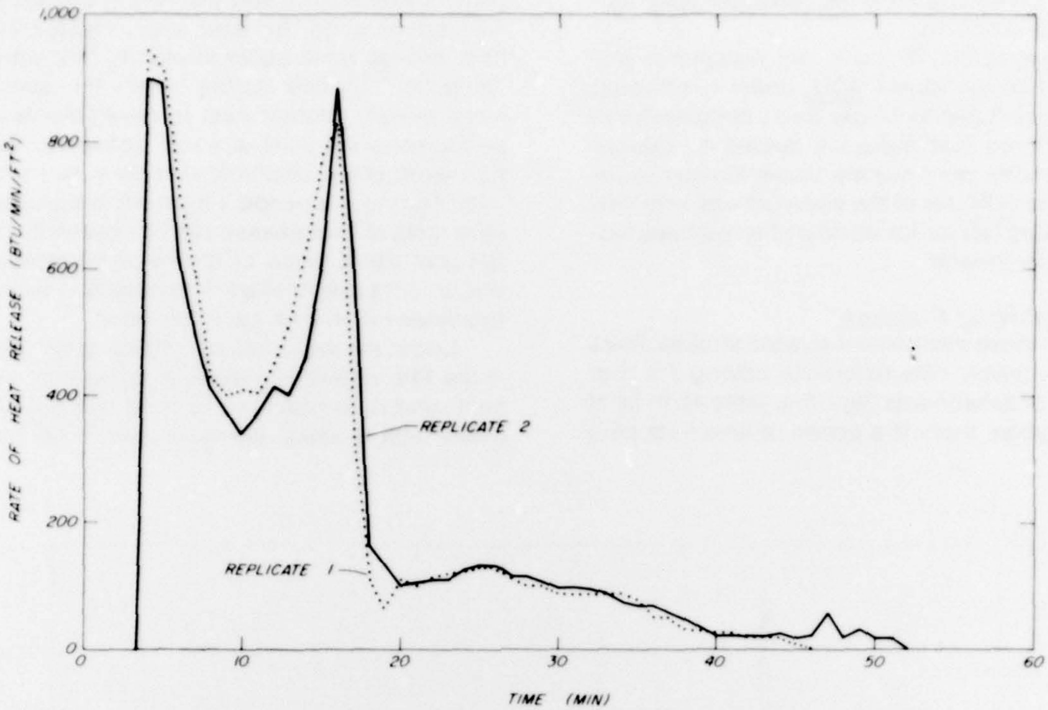

Figure 6.—Rate of heat release versus time for Commercial Board A (two replicates).
(M 146 067)

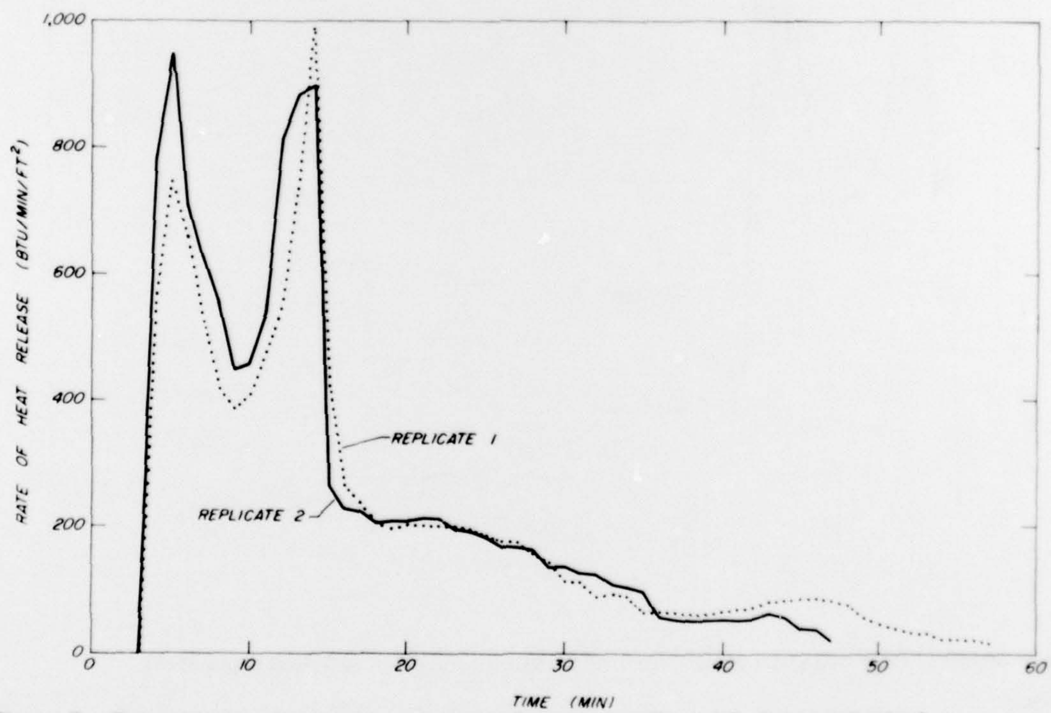

Figure 7.—Rate of heat release versus time for Commercial Board B (two replicates).
(M 146 068)

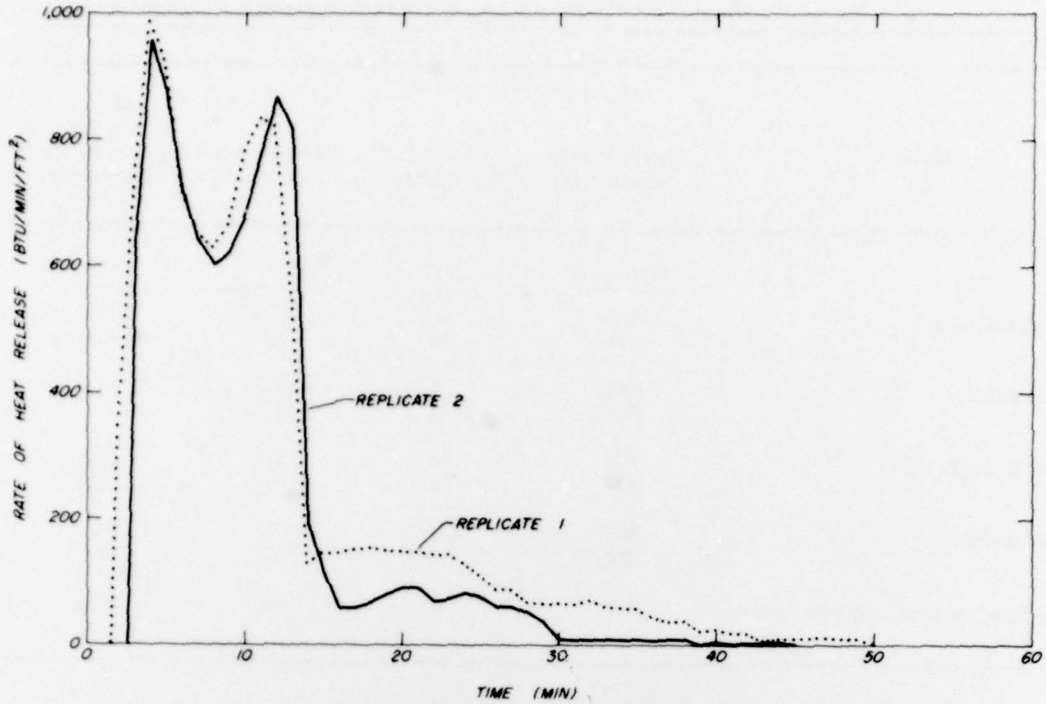

Figure 8.—Rate of heat release versus time for Commercial Board C (two replicates).

(M 146 069)

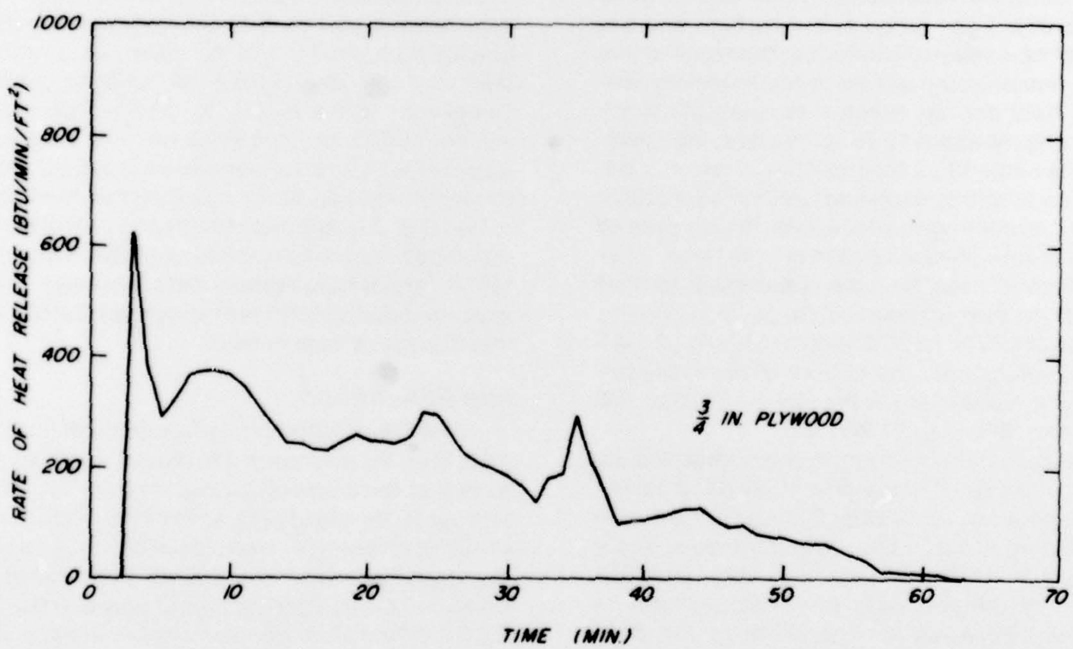

Figure 9.—Rate of heat release versus time for ¾-inch-thick Douglas-fir plywood, exterior grade (untreated).

(M 141 212)

Table 4.--Duplicate rate-of-heat-release determinations on four ½-inch structural flakeboards and a reference material

Board	Maximum heat release rate	Time of maximum rate	Average rate (first 10 min)	Percent of total area under curve in first 10 minutes
	$Btu/min/ft^2$	min	$Btu/min/ft^2$	Pct
FS structural flakeboard	966	14	422	43.0
	1,115	15	505	36.0
Commercial Board A	945	4	440	40.0
	901	4	403	37.6
Commercial Board B	994	14	371	28.9
	899	14	453	33.9
Commercial Board C	989	4	647	53.5
	958	4	573	56.4
Douglas-fir plywood, exterior grade, ¾-inch	611	3	308	27.8

peak, occurring at 4 to 5 minutes into the test, represents the heat released from flaming combustion of the specimen surface. As time goes on, a char layer forms at the surface and the rate of heat release is reduced. During all of this time, however, the sample is accumulating sensible heat and its average temperature is increasing. At about 12 to 16 minutes, the specimen is heated to a temperature at which it begins to crumble, exposing uncharred material of a relatively large surface area. Thus a second peak of rate-of-heat-release is generated. After the second peak, the heat-release rate falls off rapidly to zero. Values at both peaks are in the range of 900 to 1,100 $Btu/min/ft^2$ (17 to 21 W/cm^2). Values near the bottom of the valley between the peaks are in the range of 400 to 600 $Btu/min/ft^2$ (7.5 to 11 W/cm^2).

Replicate heat release determinations on each of the four flakeboards show good agreement between replicates. Except for Commercial Board B, all of the flakeboard types show consistency between replicates with respect to which of the two peak heat release rates is highest. However, on the basis of the data given here, it is not possible to state which of the types of flakeboard might have the best fire performance from the standpoint of rate-of-heat release characteristics. Considering previously published data (8), the flakeboards tend to have relatively high initial (flaming) rates of heat release and tend to be consumed more quickly than solid wood—for example, 1-inch-thick red oak or ¾-inch-thick exterior grade Douglas-fir plywood (fig. 9). The flakeboards are not consumed as quickly nor with heat release rates as high as tempered hardboard, but the induction period for these materials tends to be slightly longer than for plywood. In understanding the performance of all of these materials in rate-of-heat release tests, however, it is important that variations in specimen thickness and density be kept in mind.

Fire Penetration

The fire penetration performance of the ½-inch-thick FS structural flakeboard was similar to that of the commercial boards (table 5). For all boards, the steady-state char rates from 0.99 to 1.26 inch per hour were about what would be expected for a wood product of their density. Douglas-fir with a dry specific gravity of 0.6 and 6 percent moisture content would have a char rate of 1.27 inch per hour (22).

As expected, the char rate is initially higher. The production of a char layer reduces

the char rate until a steady rate is obtained. The thermocouples between the plies in the four-ply panels revealed high correlation between char depth (at 550°F) and time in all the four-ply panels. The high linear correlation in the four-ply tests indicates the constant char rate that occurs after the first ½ inch of charring. Data based on total duration of fire exposure and thickness of wood charred generally agreed with the line obtained by the least-squares analysis of the time-distance data of the three thermocouples between the plies. Some data based on time of burnthrough indicated a higher char rate at burnthrough. The initial char rate in the four-ply specimens is lower than the char rate for the one-ply specimens (table 6). This could be due to heat being conducted to the rest of the four-ply specimen instead of accumulating and increasing the temperature. A few of the char rates for the one-ply panels would be reduced slightly if only one center thermocouple is used as is the case with the four-ply panels.

Fire Endurance of Walls

In the fire endurance tests of the walls, the flakeboard interior facing was observed to begin to break up between 11 and 12 minutes and to be almost completely gone in 14 to 16 minutes. The poorer performance of the flakeboard in the large furnace compared with the performance in the small vertical furnace is possibly due to the difference in the type of burners in the two furnaces or differences in the boundary conditions of the unexposed side of the panel.

Based on area under the time-temperature curves, the actual time-temperature exposure deviated from the standard curve by +0.8 to +4.6 percent. The average internal furnace pressures were -0.002 to -0.041 inch of water near the bottom and +0.024 to +0.042 inch of water near the top. Temperatures as measured by thermocouples beneath asbestos pads on the unexposed surface were less than 250°F above initial temperatures until after burnthrough.

The performance of the FS structural flakeboard was better than or equal to the performance of the commercial flakeboards in the wall tests (table 7). The walls with ⅝-inch gypsum interior facing performed slightly better than the walls with the flakeboard as the interior facing. A previous test of ⅜-inch Douglas-fir plywood exterior sheathing and ⅜-inch gypsum interior facing resulted in a burnthrough at 29 minutes 30 seconds and structural failure at 33 minutes 30 seconds (11). These results for ⅜-inch plywood and ⅜-inch gypsum are within the range of results for ½-inch flakeboard and ⅝-inch gypsum. In general, the fire endurance of these walls with flakeboard facings were as expected for this type of wall construction.

The fire endurance of all eight walls was in excess of the 20 minutes required for exterior walls in the Minimum Property Standards for Single-and Double-Family Dwellings of the U.S. Department of Housing and Urban Development (26).

The value determined for the finish resistance provided by the FS structural flakeboard in the wall configuration tested was 10.1 minutes, slightly higher than the other boards (table 8).

Table 5. - - Fire penetration tests of ½-inch, one-ply specimens of structural flakeboards

Material	Test	Time average temperature reached 250° F above ambient[1]	Time an individual thermocouple reached		Time of burnthrough	Char rate[2]
			325° F above ambient[1]	550° F[1]		
		Min	Min	Min	Min	In./hr
FS structural flakeboard	1	11.0	11.3	13.4	15.7	2.26
	2	11.2	11.9	14.3	14.7	2.04
	3	12.0	12.9	15.3	15.9	1.87
	Average	11.4	12.0	14.3	15.4	2.05
Commercial Board A	1	11.9	12.9	15.2	- -	2.01
	2	13.0	14.5	15.6	16.0	1.95
	Average	12.4	13.7	15.4	- -	1.98
Commercial Board B	1	10.4	11.2	13.4	- -	2.24
	2	11.6	13.0	14.9	15.0	2.05
	Average	11.0	12.1	14.2	- -	2.14
Commercial Board C	1	11.6	10.2	11.7	12.3	2.51
	2	10.6	11.7	- -	11.5	2.53
	Average	11.1	11.0	- -	11.9	2.52

[1]Five thermocouples were under asbestos pads on the unexposed surface. A thermocouple was located in the center of the panel and the center of each quadrant.
[2]Computed from the time a thermocouple reached 550°F or time of burnthrough and the thickness of the panel.

Table 6. - - Fire penetration tests of 2-inch, four-ply specimens of ½-inch structural flakeboard

Material	Test	Char rate: Initial[1]	Char rate: Steady-state[2]	Char rate: Average[3]
			In./hr	
FS structural flakeboard	1	1.76	1.24	1.34
	2	1.72	1.23	1.34
	3	1.59	- -	1.38
	Average[4]	1.69	1.24	1.35
Commercial Board A	1	1.62	1.13	1.39
	2	1.57	.99	- -
	3	1.57	1.16	1.32
	Average[4]	1.59	1.07	1.36
Commercial Board B	1	1.68	1.26	1.38
	2	1.73	1.12	1.24
	Average[4]	1.70	1.17	1.31
Commercial Board C	1	1.96	1.14	1.31
	2	1.89	1.19	1.33
	Average[4]	1.92	1.16	1.32

[1]Calculated from time for thermocouple ½ in. from original exposed surface to reach 550°F.
[2]The slope of linear line obtained by least-squares analysis of times for thermocouples ½, 1, and 1½ in. from original exposed surface to reach 550°F.
[3]Calculated from total duration of fire exposure and thickness of wood charred at end of test or thickness of panel and time of burnthrough.
[4]Average is the mean of the test results except for the steady-state char rate in which it is the slope obtained from the least-squares analysis of the combined data.

Table 7. - - Summary of fire endurance of load-bearing wood-frame walls by ASTM E 119 tests

½-inch flakeboard sheathing	Interior facing	Time of structural failure	Time of burnthrough
		Min:sec	Min:sec
FS structural flakeboard	3/8-inch gypsum board	35:37	33:20
	½-inch flakeboard	30:44	31:35
Commercial Board A	3/8-inch gypsum board	35:22	33:54
	½-inch flakeboard	27:40	27:35
Commercial Board B	3/8-inch gypsum board	29:20	28:25
	½-inch flakeboard	21:13	- -
Commercial Board C	3/8-inch gypsum board	28:40	27:45
	½-inch flakeboard	25:50	26:20

Table 8 - - Finish resistance of interior fire-exposed flakeboard on wood-frame walls in ASTM E 119 furnace tests

½-Inch interior facing	Time average temperature exceeded 250° F above ambient[1]	Time single thermocouple temperature exceeded 325° F above ambient[1]
	Min	Min
FS structural flakeboard	10.4	10.1
Commercial Board A	9.1	8.9
Commercial Board B	8.0	7.7
Commercial Board C	10.2	9.8

[1]Six thermocouples were placed between the interior facing and the studs. Three were 2 ft from the top of the wall and three were 2 ft from the bottom of the wall.

Conclusions

1. The Forest Service structural flakeboard obtained a flame spread of 71, or class B, in the 25-foot rating furnace of ASTM E 84, while the three commercial boards tested were class C. By 8-foot furnace and room corner-wall tests, the fire performance of all boards was generally equivalent. Commercial Board C had the highest flame spread value in all test procedures.

2. The FS structural flakeboard was intermediate in most smoke yield characteristics obtained in the smoke density chamber test. Commercial Board C had the highest smoke yield under nonflaming exposure conditions.

3. Under exposure conditions of the FPL rate-of-heat-release test method, little difference was indicated between the four types of structural flakeboards. Results were relatively high compared to solid wood and exterior grade Douglas-fir plywood.

4. Fire penetration performance of the FS structural flakeboard was similar to that of the commercial boards. Its steady-state char rate of 1.24 inch per hour was what would be expected for a wood product of that density.

5. Fire endurance performance of load-bearing wood-frame walls constructed with FS structural flakeboard was better than or equivalent to that of the commercial flakeboards. All walls tested met the 20-minute requirement of the Minimum Property Standards for exterior walls of one- and two-family dwellings.

6. Temperature measurements between the interior facing and the wood studs indicated that ½-inch-thick FS structural flakeboard has a finish resistance of 10 minutes in a wood-stud wall with glass-fiber insulation.

Literature Cited

1. American Insurance Association.
   1967. National building code. Am. Insur. Assoc., Eng. and Safety Dep., New York. 399 p.

2. American Society for Testing and Materials.
   1970. Standard method of test for surface burning characteristics of building materials. Standard Designation E 84-70. ASTM, Philadelphia, Pa.

3. American Society for Testing and Materials.
   1973. Standard methods of fire tests of building construction and materials. Standard Designation E 119-73. ASTM, Philadelphia, Pa.

4. American Society for Testing and Materials.
   1975. Standard method of test for surface flammability of building materials using an 8-foot tunnel furnace. Standard Designation E 286-69 (reapproved 1975). ASTM, Philadelphia, Pa.

5. Brenden, J. J.
   1970. Determing the utility of a new optical test procedure for measuring smoke from various wood products. USDA For. Serv. Res. Pap. FPL 137. For. Prod. Lab., Madison, Wis.

6. Brenden, J. J.
   1973. How 14 coating systems affected smoke yield from Douglas-fir plywood. USDA For. Serv. Res. Pap. FPL 214. For. Prod. Lab., Madison, Wis.

7. Brenden, J. J.
   1973. An apparatus developed to measure the rate-of-heat release from building materials. USDA For. Serv. Res. Pap. FPL 217. For. Prod. Lab., Madison, Wis.

8. Brenden, J. J.
   1974. Rate of heat release from wood-base building materials exposed to fire. USDA For. Serv. Res. Pap. FPL 230. For. Prod. Lab., Madison, Wis.

9. Brenden, J. J.
   1975. How nine inorganic salts affected smoke yield from Douglas-fir plywood. USDA For. Serv. Res. Pap. FPL 249. For. Prod. Lab., Madison, Wis.

10. Building Officials and Code Administrators, International.
    1975. BOCA basic building code. BOCA, Chicago, Ill. 497 p.

11. Eickner, H. W.
    1975. Fire endurance of wood-frame and sandwich wall panels. J. Fire & Flammability 6(Apr.):155-190.

12. Factory Mutual Fire Insurance Co., Factory Mutual Engineering Division.
    1964. Rate of heat release of building materials from FM construction materials calorimeter. Factory Mutual Fire Insur., Co., Norwood, Mass.

13. Fang, J. B.
    1975. Fire buildup in a room and the role of interior finish materials. NBS Tech. Note 879. U.S. Dep. Comm., Natl. Bur. Stand., Washington, D.C.

14. Gross, D., J. J. Loftus, and A. F. Robertson.
    1967. A method for measuring smoke from burning materials. ASTM Spec. Tech. Pub. No. 422. Amer. Soc. Testing Mater., Philadelphia, Pa.

15. Holmes, C. A.
    1978. Room corner-wall fire tests of some structural sandwich panels and components. J. Fire & Flammability 9 (Oct.): 467-488.

16. International Conference of Building Officials.
    1976. Uniform building code. ICBO, Whittier, Calif. 704 p.

17. Lee, T. G.
    1971. Interlaboratory evaluation of smoke density chamber. NBS Tech.

Note 708. U.S. Dep. Comm, Natl. Bur. Stand., Washington, D.C.

18. Lehmann, W. F.
1977. A perpetual supply of construction sheathing panels? Plywood & Panel Mag. XVII(8):63-65.

19. Loftus, J. J., D. Gross, and A. F. Robertson.
1961. Potential heat - - a method for measuring the heat release of materials in building fires. Proc. ASTM 61:1336-1348, Amer. Soc. Testing Mater., Philadelphia, Pa.

20. National Fire Protection Association.
1976. Code for safety to life from fire in buildings and structures. No. 101. NFPA, Boston, Mass. 271 p.

21. Peters, C. C., and H. W. Eickner.
1962. Surface flammability as determined by the FPL 8-foot tunnel method. USDA For. Serv. FPL Rep. No. 2257. For. Prod. Lab., Madison, Wis.

22. Schaffer, E. L.
1967. Charring rate of selected woods - - transverse to grain. USDA For. Serv. Res. Pap. FPL 69. For. Prod. Lab., Madison, Wis.

23. Schaffer, E. L.
1976. Forest residue into structural flakeboard: A Forest Service national program. Trans. ASAE 19(3): 417-421, 427. Am. Soc. Agric. Eng., St. Joseph, Mich.

24. Southern Building Code Congress.
1973. Southern standard building code. SBCC, Birmingham, Ala.

25. U. S. Department of Agriculture, Forest Service, Forest Products Laboratory.
1967. Small tunnel-furnace test for measuring surface flammability. USDA For. Serv. Res. Note FPL-0167. For. Prod. Lab., Madison, Wis.

26. U.S. Department of Housing and Urban Development.
1973. Minimum property standards for single- and double-family dwellings, 1973 edition. U.S. Dep. Housing Urban Devel., Washington, D.C.

27. Williamson, R. B., and F. M. Baron.
1973. A corner fire test to simulate residential fires. J. Fire & Flammability 4(Apr.):99-105.

6-79-21-2.5